Prediction of Serious Arrhythmic Events After Myocardial Infarction: Signal-Averaged Electrocardiogram, Holter Monitoring and Radionuclide Ventriculography

DENNIS L. KUCHAR, MB, FRACP, CHARLES W. THORBURN, MB, FRACP, NEVILLE L. SAMMEL, MB, FRACP, FACC

Sydney, Australia

Noninvasive assessment was undertaken before hospital discharge in 210 patients who had recovered from acute myocardial infarction. This comprised signal-averaged electrocardiography, Holter monitoring and radionuclide left ventriculography. An abnormal signal-averaged electrocardiogram was defined as the presence of a low voltage signal less than 20 μV in the terminal 40 ms of the filtered QRS complex or a long filtered QRS complex >120 ms. During a follow-up period of 6 months to 2 years (median 14 months), 15 patients had arrhythmic events: eight died suddenly and seven presented with sustained, symptomatic ventricular tachycardia. Using univariate analysis, abnormalities in each of the three noninvasive tests were able to predict arrhythmic events.

Stepwise logistic regression demonstrated that each test was independently significant in predicting outcome, with a left ventricular ejection fraction <40% being the most powerful variable ($\beta = 2.8$, $p < 0.005$). This process generated an algorithm that allowed assessment of combinations of variables: the finding of an abnormal signal-averaged electrocardiogram in the presence of an ejection fraction <40% identified patients with a 34% probability of arrhythmic events. By contrast, in patients with left ventricular dysfunction but a normal signal-averaged tracing, the risk of arrhythmic events was 4% ($p < 0.001$). This combination of variables was associated with a sensitivity of 80% and a specificity of 89%. Hence, using a combination of noninvasive tests after myocardial infarction, patients can be stratified according to risk of serious arrhythmic events.

(J Am Coll Cardiol 1987;9:531–8)

The primary mechanism of sudden death occurring after recovery from myocardial infarction is thought to be ventricular tachycardia or fibrillation (1,2). Several noninvasive methods have been utilized in an attempt to reliably predict which patients are at risk of developing these arrhythmias. These have included Holter monitoring, radionuclide ventriculography, exercise testing and various clinical indexes either singly or in combination (3–8).

Using signal amplification and computerized averaging techniques, patients with ventricular tachycardia can be identified by the demonstration of low amplitude, high frequency "late potentials" (9–12). These signals are thought to represent regional slow conduction in the border zone of infarction, which is the presumed arrhythmic substrate (13–15). This technique is attractive because it is noninvasive and inexpensive to perform. However, it has had limited application as a predictor of future ventricular arrhythmias after recovery from myocardial infarction; preliminary evidence has suggested that late potentials have a high prevalence in patients with recent myocardial infarction and therefore lack specificity (16–18). In a retrospective assessment of patients studied late after myocardial infarction (19), patients with ventricular tachycardia were best characterized by the combination of findings on signal-averaged electrocardiography and abnormalities on Holter monitoring and cardiac catheterization.

The purpose of this study was to determine whether a combination of findings from signal-averaged electrocardiography, Holter monitoring and radionuclide ventriculography, performed early after recovery from acute infarction, could accurately predict which patients were likely to develop sustained ventricular tachycardia or sudden death.

From the Department of Cardiovascular Medicine, St. Vincent's Hospital, Sydney, Australia. Dr. Kuchar was supported by a Postgraduate Medical Research Scholarship from the National Health and Medical Research Council of Australia, Canberra, ACT, Australia.

Manuscript received July 14, 1986; revised manuscript received September 16, 1986, accepted October 6, 1986.

Address for reprints: Dennis L. Kuchar, MB, Electrophysiology Laboratory, Cardiac Unit, Massachusetts General Hospital, Boston, Massachusetts 02114.

0735-1097/87/$3.50

JACC Vol. 9, No. 3
March 1987:531–8

Methods

Study patients. Two hundred ten consecutive patients presenting with acute myocardial infarction were studied prospectively. These patients, who had survived the hospital phase of recovery, were primary admissions to the coronary care unit between March 1984 and September 1985. Age more than 72 years and residence outside the metropolitan area were the only criteria for exclusion. The diagnosis of acute infarction was based on the occurrence of prolonged chest pain compatible with ischemia, serial elevation of serum cardiac enzyme (creatine kinase [CK]-MB) levels and evolving electrocardiographic changes consistent with Q wave or non-Q wave infarction.

Signal-averaged electrocardiogram. All patients underwent signal-averaged electrocardiography before hospital discharge 11 ± 6 days (range 7 to 40) after initial presentation. Most tests were done before day 14 and were coordinated to occur within 48 hours of Holter monitoring and left ventriculography. One patient's signal-averaged recording was delayed until day 40 because he was treated with intraaortic balloon pumping for cardiac failure for 2 weeks.

Signal-averaged electrocardiography was performed using the Arrhythmia Research Technology high resolution electrocardiogram based on methods previously described by Simson (9) and Denes et al. (11). The electrocardiogram was recorded during sinus rhythm using standard bipolar orthogonal leads X, Y and Z in an unshielded room. Signals from 200 to 300 beats were amplified, digitized, averaged and then filtered with a bidirectional filter with a high bandpass frequency of 40 Hz. The use of this filter eliminates the artifact of filter ringing seen with commonly used digital filters (9). The filtered leads were combined into a vector magnitude, $\sqrt{x^2+y^2+z^2}$, a measure of the high frequency content from all three leads (Fig. 1). The amplitude of signals (expressed as root mean square voltage) in the last 40 ms of the filtered QRS complex and the duration of this complex were determined by computer algorithm. In previous studies (9,11,15), abnormalities of each of these variables were found to identify patients with ventricular tachycardia. Therefore, these variables were used in this study to define abnormal signal-averaged electrocardiographic tracings: a low voltage signal (<20 μV) in the last 40 ms of the filtered QRS complex, also termed "late potential," and a long filtered QRS complex (>120 ms) were considered abnormal. Patients with bundle branch block on the standard electrocardiogram were not considered in the analysis of the signal-averaged tracing.

Holter monitoring. Twenty-four hour ambulatory Holter electrocardiographic recordings were obtained within 48 hours of signal-averaged electrocardiography. Analysis was performed using a standard recorder (Del Mar Avionics), and ventricular arrhythmias were classified according to the Lown grading system (3). Complex ventricular ectopic activity was defined as the presence of Lown grade 3 to 5 ventricular premature complexes; frequent ventricular ectopic activity was defined as 10 or more premature complexes/h. Nonsustained ventricular tachycardia was defined as three or more consecutive ventricular premature complexes with a rate greater than 120/min (Lown grade 4b).

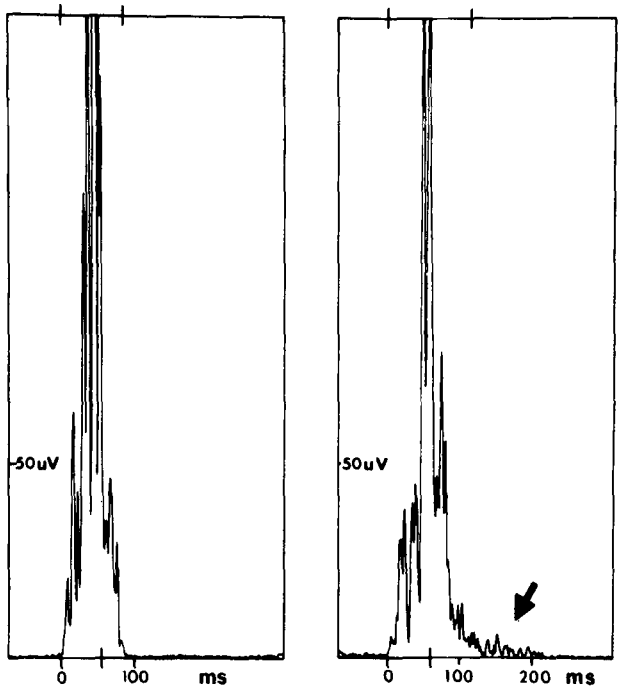


Figure 1. Signal-averaged electrocardiogram recorded during sinus rhythm in a normal subject (**left**), and in a patient who had previously documented ventricular tachycardia after myocardial infarction (**right**). There is a long, low, late amplitude signal (**arrow**) at the end of the filtered QRS complex in the patient with a history of ventricular tachycardia.

Left ventriculography. Left ventricular ejection fraction was assessed by radionuclide ventriculography before hospital discharge in 176 patients and by single plane cineangiography in 34 who underwent coronary angiography. Left ventricular aneurysm was defined as the presence of regional paradoxic systolic wall motion.

Follow-up and study end points. Patients were recalled for clinical reassessment at regular intervals up to 2 years after hospital discharge. All patients were followed up for a minimum of 6 months (median 14 months). When a patient died, an eyewitness account was sought. Autopsy was performed where possible. An arrhythmic event was defined as sudden unexpected death or occurrence of symptomatic or sustained ventricular arrhythmia. Sustained ventricular arrhythmia was defined as spontaneous ventricular tachycardia or fibrillation lasting more than 30 seconds or necessitating cardioversion because of hemodynamic collapse. This definition was also used to include patients who sub-

sequently presented with witnessed syncope and were found to have inducible sustained ventricular tachycardia at electrophysiologic study (using a protocol of a maximum of two right ventricular extrastimuli at two drive cycle lengths), in the absence of other identifiable causes for syncope. Sudden death was defined as witnessed death within 1 hour of the onset of symptoms in a clinically stable patient, or unexpected death occurring during sleep. Patients in whom electrocardiographic monitoring performed while the patient was dying revealed a primary arrhythmia other than ventricular tachycardia or fibrillation were not classified as having an arrhythmic event.

Treatment was not standardized in this study and was left to the discretion of attending physicians. The results of signal-averaged electrocardiography were not disclosed.

Statistical analysis. Data analysis was performed using Student's *t* test, and the chi-square method where appropriate. Data were expressed as mean ± 1 SD unless otherwise specified. Stepwise logistic regression (20) was used to determine the prognostic significance of abnormal results on signal-averaged electrocardiography and Holter monitoring and of left ventricular dysfunction simultaneously. This technique determines which variables are independently significant and ranks them by assigning coefficients (β) to them. An equation is generated that allows assessment of risk for an individual patient based on the results of this analysis, such that the probability of an arrhythmic event is

$$P(AE) = \frac{e^{\text{logit } y}}{1 + e^{\text{logit } y}}$$

where logit $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_n x_n$.

For a given variable x, the larger the value of β, the more it influences the predicted probability of an arrhythmic event. Sensitivity is the percent of patients who had both an arrhythmic event and an abnormal test result; specificity is the percent of patients who did not have an arrhythmic event and had a negative test result. The odds ratio describes the risk of an event if a test variable is abnormal relative to the risk if the variable is normal. The positive predictive value was defined as the percent of patients with an abnormal test who later developed an arrhythmic event.

Results

Description of study patients (Table 1). Of the 210 patients entering this study, 76 had an anterior wall infarct, 69 an inferior wall infarct and the remaining 55 a subendocardial (non-Q wave) infarct. Ten additional patients had bundle branch block on standard electrocardiography. During the 14 month median follow-up period, there were eight sudden deaths and seven patients presented with sustained symptomatic ventricular tachycardia. The mean cycle length of ventricular tachycardia was 368 ± 33 ms (rate 164 ± 14 beats/min). In three patients, this arrhythmia was associated with syncope, in one patient it was incessant and led to progressive cardiogenic shock in 72 hours and in three patients it was well tolerated. All arrhythmic events occurred within 6 months of hospital discharge (mean 1.6 ± 0.2, range 0.5 to 4). Only one of these seven patients with organized ventricular tachycardia had been taking an antiarrhythmic medication (quinidine sulfate) because of prior documented complex ventricular ectopic activity; two pa-

Table 1. Clinical and Study Characteristics of 220 Patients With and Without Arrhythmic Events

	Arrhythmic Event (n = 15)	No Arrhythmic Event (n = 195)	p Value
Clinical data			
Age (yr)	65 ± 5	58 ± 10	NS
Men	11	152	NS
Anterior MI	8	68	NS
Transmural MI	12	134	NS
Killip class III-IV	4	17	NS
Peak CK-MB (IU/liter)	157 ± 75	102 ± 88	<0.001
Signal averaged ECG (n = 200)			
Abnormal tracing	13	65	<0.001
Voltage for last 40 ms (μV)	10.2 ± 8.0	33.5 ± 23.9	<0.001
Filtered QRS (ms)	126 ± 14	105 ± 12	<0.001
Holter/monitoring (n = 206)			
≥10 VPCs/h	1	14	NS
Lown grade 3–5	11	62	<0.005
Left ventriculography (n = 210)			
LVEF <40%	13	51	<0.001
Aneurysm	3	60	NS

CK-MB = creatine kinase-MB fraction; ECG = electrocardiogram; LVEF = left ventricular ejection fraction; MI = myocardial infarction; VPCs = ventricular premature complexes.

tients, who died suddenly, were also taking a type I agent. In addition, 13 patients had recurrent myocardial infarction, and coronary revascularization was performed in 35 patients. Clinical characteristics comparing patients with and without arrhythmic events are summarized in Table 1. Patients who had an arrhythmic event were noted to have significantly higher peak serum creatine kinase values.

Signal-averaged electrocardiography. Of the 210 patients entered into the study, 10 had bundle branch block and were not analyzed by the signal-averaging technique. Seventy-eight patients (39%, group I) had an abnormal signal-averaged electrocardiogram: of these, 76 had a late potential and 27 had a long filtered QRS complex. The remaining 122 patients (group II) had a normal tracing. Clinical characteristics of patients according to the findings on signal-averaged electrocardiography are illustrated in Table 2. Group I patients tended to have higher peak CK values and more often had inferior transmural infarction. There was a tendency for group II patients to be treated with a beta-receptor blocker after hospital discharge, and these patients were more likely to subsequently undergo coronary artery bypass surgery (Table 2). Empiric antiarrhythmic therapy was prescribed equally in each group of patients. Nine patients (5% of the study group) were taking an antiarrhythmic agent at the time of signal-averaged electrocardiography because of atrial arrhythmias or the occurrence of complex ventricular ectopic activity in the coronary care unit: one patient was taking amiodarone and the remaining eight were receiving a type I antiarrhythmic agent. The rate of recurrent myocardial infarction was similar in both groups (3% in group I versus 7% in group II).

Thirteen patients (17%) in group I had an arrhythmic event (six patients died suddenly, including three with documented ventricular fibrillation, and seven had spontaneous ventricular tachycardia), compared with one patient (1%) in group II with a normal tracing (odds ratio 23.6, $p < 0.001$); this latter patient was witnessed to die suddenly, but no electrocardiographic monitoring was available. One additional patient, who died suddenly, had bundle branch block and was excluded from analysis. The finding of a late potential (irrespective of the filtered QRS duration) identified 93% of patients with an arrhythmic event, with a specificity of 65% and predictive value of 17%. The specificity of an abnormal signal-averaged electrocardiogram rose to 90% when both a late potential and a long filtered QRS complex were found; this combined abnormality had a positive predictive value of 28%, but it identified only 50% of patients with an arrhythmic event. Voltage in the last 40 ms of the QRS complex was significantly lower in patients with an arrhythmic event (10.2 ± 8.0 versus 33.5 ± 23.1 μV, $p < 0.001$) and filtered QRS duration was longer in these patients (126 ± 20 versus 105 ± 12 ms, $p < 0.001$) than in patients without an arrhythmic event.

Holter monitoring. A suitable 24 hour Holter electrocardiographic tracing was obtained from 206 patients. Complex ventricular ectopic rhythm was recorded in 73 patients (35%); of these, 8 had nonsustained ventricular tachycardia. In addition, 15 patients had frequent ventricular premature complexes. Complex ventricular premature complexes were more commonly found in patients with an arrhythmic event: 71% of patients with an arrhythmic event had complex ectopic activity compared with 32% of patients who were event-free ($p < 0.005$). The incidence of arrhythmic events in patients with complex ventricular ectopic activity was 13% (odds ratio 4.3, $p < 0.05$). However, the solitary finding of either nonsustained ventricular tachycardia or frequent unimorphic ventricular premature complexes failed to identify patients with an arrhythmic event.

Left ventriculography. Sixty-four patients (30%) had a left ventricular ejection fraction <40%, and 63 had a left ventricular aneurysm. The incidence of arrhythmic events among patients with an ejection fraction <40% was 20%

Table 2. Clinical Features of 220 Patients With a Normal (Group II) or Abnormal (Group I) Signal-Averaged Electrocardiogram

	Group I (n = 78)	Group II (n = 122)	p Value
Clinical			
Age (yr)	59 ± 9	58 ± 10	NS
Men	67	96	NS
Anterior MI	25	52	<0.01
Transmural MI	65	76	NS
Killip class III-IV	9	12	NS
Peak CK-MB (IU/liter)	134 ± 88	92 ± 86	<0.001
LVEF (%)	43 ± 13	49 ± 13	<0.001
Treatment			
Streptokinase	7	12	NS
Beta-blocker	21	58	<0.005
Antiarrhythmic	5	4	NS
Coronary artery bypass grafting	6	29	<0.005

Abbreviations as in Table 1.

Table 3. Prediction of Arrhythmic Events: Multivariate Analysis

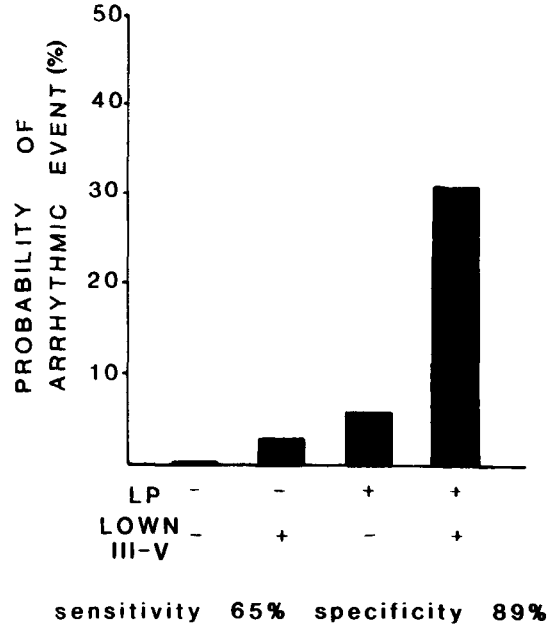
	No. of Patients With Abnormality	Odds Ratio	β	p Value
Abnormal signal-averaged ECG*	78	23.6	2.0	0.01
Left ventricular ejection fraction <40%	64	17.9	2.8	<0.005
Complex ventricular ectopic activity†	73	7.6	1.5	0.04

*Voltage in the last 40 ms of the filtered QRS <20 μV or filtered QRS duration >120 ms, or both; †Lown grade III-V ventricular arrhythmia.

(odds ratio 17.9, $p < 0.001$). Only three patients with a left ventricular aneurysm had an arrhythmic event at follow-up. Ninety-two percent of patients with an arrhythmic event had an ejection fraction <40% compared with 26% of those who were event-free ($p < 0.001$).

Predictors of arrhythmic events (Table 3). Stepwise logistic regression was used to construct a model for predicting arrhythmic events using three variables: abnormal signal-averaged electrocardiogram, complex ventricular ectopic activity on Holter monitoring and a left ventricular ejection fraction <40%. All three variables were found to be independently significant with the ejection fraction being the most powerful variable in the model ($\beta = 2.8$, $p < 0.005$). Because of the independent nature of these variables, combinations of variables were then evaluated.

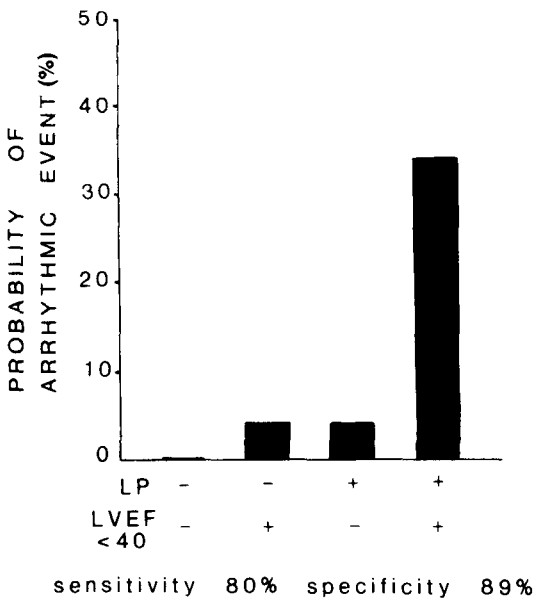
Figure 2. Predictive value of signal-averaged electrocardiography and Holter monitoring. **Column bars,** Probability of an arrhythmic event depending on whether each of the test variables was present (+) or absent (−). Lown III-V = complex ventricular ectopic activity (according to Lown grading 3–5) on Holter monitoring; LP = abnormal signal-averaged electrocardiogram (includes the finding of a low voltage signal (<20 μV) in the last 40 ms of the filtered QRS or a long filtered QRS).



Signal-averaged electrocardiography and Holter monitoring (Fig. 2). No arrhythmic events occurred in patients with a normal signal-averaged electrocardiogram who also had no evidence of complex ventricular ectopic activity. The presence of either an abnormal signal-averaged electrocardiogram or complex ectopic activity without the other variable was associated with a low probability (3 to 6%) of an arrhythmic event. The combination of these two variables, however, was associated with a 31% incidence of arrhythmic events. The sensitivity of this combined variable was 65% and the specificity was 89%.

Signal-averaged electrocardiography and left ventriculography (Fig. 3). Two hundred patients had both of these studies. Patients with a normal signal-averaged electrocardiogram and left ventricular ejection fraction >40% did not have an arrhythmic event. The presence of either an abnormal signal-averaged electrocardiogram or an ejection fraction <40% without the other was associated with a 4% probability of an arrhythmic event. The combination, how-

Figure 3. Predictive value of abnormal signal-averaged electrocardiogram (LP) and left ventricular ejection fraction (LVEF) <40%.



JACC Vol. 9, No. 3
March 1987:531–8

ever, was associated with a 34% incidence rate of events with a sensitivity of 80% and specificity of 89%.

Interrelation among signal-averaged electrocardiography, Holter monitoring and left ventricular dysfunction. The prevalence of complex ventricular ectopic activity was similar in patients with a normal signal-averaged electrocardiogram and those with an abnormal tracing (34% versus 37%, p = NS); but it was more often present in patients with an ejection fraction <40% than in those with good left ventricular function (48% versus 27%, $p < 0.005$). Patients with an abnormal signal-averaged electrocardiogram were also more likely to have left ventricular dysfunction; 41% of patients with an abnormal signal-averaged electrocardiogram had an ejection fraction <40%, compared with 22% of patients with a normal signal-averaged electrocardiogram ($p < 0.01$).

Discussion

Signal-averaged electrocardiography. This study applies several principles that have been recently documented in patients with known ventricular tachycardia to a large group of patients with recent myocardial infarction studied in a prospective fashion. Signal-averaged electrocardiography has been previously shown (9–15) to distinguish patients with from those without ventricular tachycardia, in the setting of chronic ischemic heart disease. It has also been shown (19,21) to identify patients with ventricular tachycardia independent of the presence of left ventricular dysfunction and the finding of complex ventricular ectopic activity. Combinations of either of these variables with the results of signal-averaged electrocardiography have been shown (19) to improve ability to identify patients with ventricular tachycardia. In the postinfarction patients described in this study, the occurrence of sustained ventricular tachycardia or sudden death was best predicted by the finding of an abnormal signal-averaged electrocardiogram in the presence of significant left ventricular dysfunction.

One criticism of the use of signal-averaged electrocardiography in predicting events after myocardial infarction is the poor specificity of late QRS potentials; using several other techniques, investigators (17,22,23) have reported their presence in up to 50% of patients after acute infarction. Gomes et al. (17) assessed the prognostic significance of the finding of late potentials during the early postinfarction period. The presence of a low voltage signal in the terminal QRS complex identified patients with nonsustained and sustained ventricular tachycardia during the late in-hospital period. Breithardt et al. (23) found a relation between the duration of low amplitude signals at the end of the filtered QRS complex and the later incidence of spontaneous symptomatic ventricular tachycardia. In their study, quantitation of the terminal QRS voltage was not performed; this variable, together with assessment of the total filtered QRS duration, has been shown to best differentiate patients with ventricular tachycardia from those without this arrhythmia (9). For this reason, these two variables were used to attempt to predict outcome. The finding of a late potential, defined by voltage criteria, in addition to the finding of a long filtered QRS complex, was a highly specific finding; however, only one-half of the patients with an arrhythmic event had both of these variables.

Some studies (16,21) have also suggested that the presence of late potentials and of complex ventricular ectopic activity is related to the degree of left ventricular dysfunction and to the extent of wall motion abnormalities. In our study, however, multivariate analysis demonstrated the independent nature of these variables in the prediction of serious arrhythmic events during the first 6 months after hospital discharge in patients with an otherwise uncomplicated course. By combining the information from these investigations, the specificity of an abnormal signal-averaged electrocardiogram became very high (89%). There is indeed a scientific basis for this phenomenon. As proposed by Kanovsky et al. (19), the finding of complex or frequent ventricular ectopic activity identifies those patients likely to have a "trigger" for the initiation of ventricular tachycardia, in the presence of a defined electrical substrate, which is represented by the late potential. Because of the well known variability of the frequency and complexity of ventricular ectopic activity on day to day assessment (24), this relation may have improved with longer periods of monitoring.

Left ventricular dysfunction. Patients with depressed left ventricular function due to prior myocardial infarction, especially those with a well defined left ventricular aneurysm, have been shown to be the most likely candidates for reentrant sustained ventricular tachycardia (19,25,26). Therefore, it is not surprising that such patients will be more likely to develop arrhythmic events during the first 6 months after myocardial infarction. However, this study showed that a relatively large group of patients have a very low incidence of arrhythmic events, despite marked depression of left ventricular function; these patients are characterized by the absence of late potentials, which have been shown to represent the substrate for reentrant ventricular arrhythmias. Such patients are at no greater risk of ventricular arrhythmias or sudden death than are patients with a normal ejection fraction. Although left ventricular ejection fraction was the most powerful predictor of arrhythmic outcome, left ventricular dysfunction is generally not reversible. Because the late potential represents the presumed electrical substrate for postinfarction ventricular tachycardia, therapy specifically directed toward altering the electrical properties of such tissue may be effective in influencing outcome.

Limitations. In addition to identifying an electrical sub-

strate for a reentrant ventricular tachyarrhythmia, it may be important to consider the risk of recurrent ischemia, which may also cause sudden death. A combination of exercise testing and signal-averaged electrocardiography may be a useful noninvasive means of identifying the presumed mechanisms for sudden arrhythmic death in patients after infarction.

Although drug therapy was not controlled in this study, the prevalence of empiric antiarrhythmic therapy was low, and the attending physicians did not know the results of the signal-averaged electrocardiogram. The greater tendency to use of beta-blocker therapy and coronary artery bypass surgery among patients with a normal signal-averaged electrocardiogram may be due to the generally lower incidence of depressed left ventricular function in this group.

Clinical implications. Although several recent reports (27–29), have suggested that patients at high risk for arrhythmic events can be identified by their response to programmed ventricular stimulation, this is an invasive procedure and therefore not ideally suited as a screening test in large numbers of patients with recent myocardial infarction. Noninvasive testing is obviously more desirable if it can be shown to be comparatively reliable. This study shows that with an assessment of three noninvasive variables, a useful algorithm can be applied for identifying the risk of individual patients after infarction. The combination of an abnormal signal-averaged electrocardiogram and a left ventricular ejection fraction <40% identified a very high risk group of patients for the subsequent development of sudden death or ventricular arrhythmias; such patients would be ideally suited for intervention trials with new antiarrhythmic agents or antitachycardia devices.

References

1. Ruskin JN, Di Marco JP, Garan H. Out-of-hospital cardiac arrest. Electrophysiologic observations and selection of long-term antiarrhythmic therapy. N Engl J Med 1980;303:607–13.
2. Kempf FC, Josephson ME. Cardiac arrest recorded on ambulatory electrocardiograms. Am J Cardiol 1984;53:1577–82.
3. Lown B, Wolf M. Approaches to sudden death from coronary artery disease. Circulation 1971;44:130–40.
4. Kotler MN, Tabatznick B, Mower MM, Tominaga S. Prognostic significance of ventricular ectopic beats with respect to sudden death in the late post infarction period. Circulation 1973;47:959–66.
5. Bigger JT, Fleiss JL, Kleiger R, Miller JP, Rolnitzky LM and the Multicenter Postinfarction Research Group. The relationships among ventricular arrhythmias, left ventricular dysfunction and mortality in the 2 years after myocardial infarction. Circulation 1984;69:250–8.
6. Schulze RA, Strauss HW, Pitt B. Sudden death in the year following myocardial infarction. Am J Med 1977;62:192–9.
7. Mukharji J, Rude RE, Poole WE, et al. Risk factors for sudden death after acute myocardial infarction: two year follow up. Am J Cardiol 1984;54:31–6.
8. Theroux P, Waters DD, Halphen C, Debaisieux JC, Mizgala HF. Prognostic value of exercise testing soon after myocardial infarction. N Engl J Med 1979;301:341–5.
9. Simson MB. Use of signals in the terminal QRS complex to identify patients with ventricular tachycardia after myocardial infarction. Circulation 1981;64:235–42.
10. Rozanski JJ, Mortara D, Myerburg RJ, Castellanos A. Body surface detection of delayed depolarizations in patients with recurrent ventricular tachycardia and left ventricular aneurysm. Circulation 1981;63:1172–8.
11. Denes P, Santarelli P, Hauser RG, Uretz EF. Quantitative analysis of the high frequency components of the terminal portion of the body surface QRS in normal subjects and in patients with ventricular tachycardia. Circulation 1983;67:1129–38.
12. Breithardt G, Becker R, Seipel L, Abendroth RR, Ostermeyer J. Noninvasive detection of late potentials in man—a new marker for ventricular tachycardia. Eur Heart J 1981;2:1–11.
13. Fontaine G, Frank R, Gallais Hammono F, Allali I, Phan-Thuc H, Grosgogeat Y. Electrocardiographie des potentiels tardifs du syndrome de post-excitation. Arch Mal Coeur 1978;78:854–64.
14. Berbari EJ, Scherlag BJ, Hope RR, Lazzara R. Recordings from the body surface of arrhythmogenic ventricular activity during the ST segment. Am J Cardiol 1978;41:697–702.
15. Simson MB, Untereker WJ, Spielman SR, et al. Relation between late potentials on the body surface and directly recorded fragmented electrograms in patients with ventricular tachycardia. Am J Cardiol 1983;57:105–12.
16. Breithardt G, Borggreffe M, Karbenn A, Abendroth AR, Yey HL, Seipel L. Prevalence of late potentials in patients with and without ventricular tachycardia: correlation with angiographic findings. Am J Cardiol 1982;49:1932–7.
17. Gomes JA, Mehra R, Barreca P, El-Sherif N, Harriman R, Holtzmann R. Quantitative analysis of the high frequency components of the signal-averaged QRS complex in patients with acute myocardial infarction: a prospective study. Circulation 1985;72:105–11.
18. Abdollah H, Richards DA, Dool A, et al. Signal averaged ECG in post myocardial infarction patients (abstr). Circulation 1983;68(suppl III):III-172.
19. Kanovsky MS, Falcone RA, Dresden CA, Josephson ME, Simson MB. Identification of patients with ventricular tachycardia after myocardial infarction: signal-averaged electrocardiogram, Holter monitoring and cardiac catheterization. Circulation 1984;70:264–70.
20. Anderson S, Augier A, Hanck W, Oaks D, van Dale W, Weisberg N. Statistical Methods for Comparative Studies. New York: John Wiley & Sons, 1980:161–77.
21. Denes P, Uretz E, Santarelli P. Determinants of arrhythmogenic ventricular activity detected on the body surface QRS in patients with coronary artery disease. Am J Cardiol 1984;53:1519–23.
22. Denniss AR, Cody DV, Fenton SM, Richards DA. Significance of delayed activation potentials in survivors of myocardial infarction (abstr). J Am Coll Cardiol 1983;1:582.
23. Breithardt G, Schwarzmeier J, Borggreffe M, Haerten K, Seipel L. Prognostic significance of late ventricular potentials after acute myocardial infarction. Eur Heart J 1983;487–95.
24. Morganroth J, Michelson EL, Horowitz LN, Josephson ME, Pearlman AS, Dunkman WB. Limitations of routine long-term electrocardiographic monitoring to assess ventricular ectopic frequency. Circulation 1978;58:408–12.
25. Dubnow MH, Burchell HB, Titus JL. Post infarction ventricular aneurysm: a clinicomorphologic and electrocardiographic study of 80 cases. Am Heart J 1965;70:753–60.
26. Califf RM, Burkes JM, Behar VS, Margolis JR, Wagner GS. Relationships among ventricular arrhythmias, coronary artery disease, and

angiographic and electrocardiographic indicators of myocardial fibrosis. Circulation 1978;57:725–80.

27. Hamer A, Vohra J, Hunt D, Sloman G. Prediction of sudden death by electrophysiologic studies in high risk patients surviving acute myocardial infarction. Am J Cardiol 1982;50:223–29.

28. Richards DA, Cody DV, Denniss AR. Russell PA, Young AA, Uther JB. Ventricular electrical instability: a predictor of death after myocardial infarction. Am J Cardiol 1983;51:75–80.

29. Waspe LE, Seinfeld D, Ferrick A, Kim SG, Matos JA, Fisher JD. Prediction of sudden death and spontaneous ventricular tachycardia in survivors of complicated myocardial infarction: value of the response to programmed stimulation using a maximum of three ventricular extrastimuli. J Am Coll Cardiol 1985;5:1292–301.